APPLICATION

FOR

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TITLE: EROSION MITIGATION FOR COLLECTOR OPTICS
USING ELECTRIC AND MAGNETIC FIELDS

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EROSION MITIGATION FOR COLLECTOR OPTICS USING ELECTRIC AND MAGNETIC FIELDS

BACKGROUND

[0001]   Lithography is used in the fabrication of semiconductor devices. In lithography, a light sensitive material, called a "photoresist", coats a wafer substrate, such as silicon. The photoresist may be exposed to light reflected from a mask to reproduce an image of the mask. When the wafer and mask are illuminated, the photoresist undergoes chemical reactions and is then developed to produce a replicated pattern of the mask on the wafer.

[0002]   Extreme Ultraviolet (EUV) lithography is a promising future lithography technique. EUV light may be produced using a small, hot plasma that will efficiently radiate at a desired wavelength, e.g., in a range of approximately 11 nm to 15 nm. The plasma may be created in a vacuum chamber, typically by driving a pulsed electrical discharge through the target material or by focusing a pulsed laser beam onto the target material. The light produced by the plasma is then collected by nearby mirrors and sent downstream to the rest of the lithography tool.

[0003]   The hot plasma tends to erode materials nearby, e.g., the electrodes in electric-discharge sources. The

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eroded material may coat the collector optics, resulting in a loss of reflectivity and reducing the amount of light available for lithography.

BRIEF DESCRIPTION OF THE DRAWINGS

[0004]   Figure 1 is a block diagram of a lithography system.

[0005]   Figure 2 is a sectional view of a light source chamber.

[0006]   Figure 3 is a sectional view of a light source chamber including a magnetic field generator in a Discharge Produced Plasma (DPP) system.

[0007]   Figure 4A is a side view of a magnetic field generator for collector optics.

[0008]   Figure 4B illustrates the effect of a magnetic field on debris particles.

[0009]   Figure 5 is a sectional view of a light source chamber including a magnetic field generator in a Laser Produced Plasma (LPP) system.

[0010]   Figure 6A is a perspective view of nested collector optics and illustrates the effect of a generated magnetic field on a debris particle.

[0011]   Figure 6B is an end view of the nested collector optics and magnetic field of Figure 6A.

[0012]   Figure 7A is a perspective view of nested collector optics with a magnetic field generator according to another embodiment.

[0013]   Figure 7B illustrates a dipole field generated by a wire in the nested collector optics of Figure 7B.

[0014]   Figure 8 is a sectional view of nested collector optics with a magnetic field generator according to another embodiment.

[0015]   Figure 9 is a perspective view of a light source chamber including collector optics and a foil trap to trap debris.

DETAILED DESCRIPTION

[0016]   Figure 1 shows a lithography system 100. A wafer, coated with a light sensitive coating ("photoresist"), and a mask may be placed in a lithography chamber 105. The pressure in the lithography chamber 105 may be reduced to a near vacuum environment by vacuum pumps 110. A light source chamber 115, which houses a light source, is connected to the lithography chamber 105. The pressure in the light source chamber may also be reduced to a near vacuum environment by the vacuum pumps 110. The

light source chamber and lithography chamber may be
separated by a valve 120 which may be used to isolate the
chambers. This allows for different environments within
the different chambers.

[0017]   The light source chamber 115 may be an EUV
chamber, which houses an EUV light source. A power supply
125 is connected to the EUV chamber to supply energy for
creating an EUV photon emitting plasma, which provides EUV
light for lithography. The EUV light may have a wavelength
in a range of 11 nm to 15 nm, e.g., 13.5 nm. The source
may be a plasma light source, e.g., a laser plasma source
or a pinch plasma source. Plasma-producing components,
such as electrodes, in the EUV source may excite a gas,
such as Xenon, to produce EUV radiation. The EUV chamber
may be evacuated by the vacuum pumps 110.

[0018]   Figure 2 shows a sectional view of an exemplary
EUV chamber. The light source, in this case a discharge
produced plasma (DPP) source 205, and collector mirrors 210
for collecting and directing the EUV light 215 for use in
the lithography chamber 105 are inside the EUV chamber.
The collector mirrors 210 may have a nominally
conical/cylindrical structure.

[0019]   Tungsten (W) or other refractory metals or alloys
that are resistant to plasma erosion may be used for

components in the EUV source. However, plasma erosion may still occur, and the debris produced by the erosion may be deposited on the collector mirrors 210. Debris may be produced from other sources, e.g., the walls of the chamber. Debris particles may coat the collector mirrors, resulting in a loss of reflectivity. Fast atoms produced by the electric discharge (e.g., Xe, Li, Sn, or In) may sputter away part of the collector mirror surfaces, further reducing reflectivity.

[0020]   In an embodiment, a magnetic field is created around the collector mirrors to deflect charged particles and/or highly energetic ions 220 and thereby reduce erosion. A magnetic field may be generated using a solenoid structure. This magnetic field may be used to generate Lorentz force when there is a charged particle traveling perpendicular or at certain other angles with respect to the magnetic field direction. By applying high current (I) and many loops around the ferromagnetic tube, a high magnetic field can be generated.

[0021]   Figure 3 shows an exemplary arrangement including a magnetic field generator 405 added in the collector optics. Figure 4A is enlarged view of a single collector element with the magnetic field generator. The magnetic field generator includes a ferromagnetic core 510 and a

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coil 520 with many loops to improve the field strength.

High velocity particles or ions 530 may be deflected away

from the surface of the collector optics by the magnetic

field 540 as shown in Figure 4B, thereby reducing any

sputtering or erosion of the surface material. A cooling

system may be included around to the solenoid structure for

thermal management.

[0022]   In an alternative embodiment, a magnetic field

generator 570 may be implemented in a laser produced plasma

(LPP) system.

[0023]   The collector optics may have a nested shell

arrangement, as shown in Figures 6A and 6B. The collector

optics may include an inner shell 602, and outer shell 604,

with one or more intervening shells 606. Each of the

shells may have a reflective inner surface (i.e., facing

toward the center of the shell structure) and a non-

reflective backside.

[0024]   An azimuthal magnetic field 608 may be produced

by passing a current down the length of the inner and outer

shells 602, 604, or alternatively, separate extra-thick

shells concentric with the actual reflective shells. Such

a field would then act to carry a positively charged ion

610 towards the non-reflective backside of each collector

shell.

[0025]   In an exemplary system, inner and outer current-carrying shells (coaxial with the reflective shells) of 1cm thick copper are provided. In an embodiment, the outer shell has a radius of 10cm and a cross-sectional area (2 pi r dr) of approximately 6000cm^2, and a length of 20cm. The amount of current such a shell can tolerate is given by:

[0026]   R = ? L/A = $2 \cdot 10^{-8}$ * 0.2m / $6 \cdot 10^{-3}$ m^2 ~ $6.6 \cdot 10^{-3}$? .

[0027]   Current: I = sqrt(P/R) = sqrt(1kW/$6.6 \cdot 10^3$?) = 39kA.

[0028]   This assumes that the shell can tolerate a heat load of 1kW over the shell. This is only a small fraction of heat delivered by a high volume manufacturing (HVM) source (100s of kW) and corresponds to a heat loading of only 1kW/(2 pi * 10cm*20cm) ~ 1 W/cm^2.

[0029]   Using Ampere's law, the strength of the magnetic field produced using this current is given by:

[0030]   B ~ $?_0$I/4?r = $1.26 \cdot 10^{-6}$? $?$m * $3.9 \cdot 10^4$ A / (4?*0.1m) = 0.04 T

[0031]   Assuming a radius of 1m is required to match the curvature of the shell, the magnetic field could deflect a single-charge Xe ion with a speed given by:

[0032]   R = mV / qB -> V = qBR/m = $1.6 \cdot 10^{-19}$ C * 0.04 T * 1m / $2 \cdot 10^{-25}$ kg = $3.2 \cdot 10^4$ m/s

[0033]   In eV: KE = 0.5 * $2 \cdot 10^{-25}$ kg * $(3.2 \cdot 10^4$ m/s$)^2$ *

$6.3 \cdot 10^{18}$ eV/J = **640 eV**

[0034]   Such energies may cover the vast majority of ions

discharged from typical EUV sources. The small minority

with energies of several keV might be slowed to 500eV or

less by the time they reach the collector section by

introducing a buffer gas.

[0035]   In an embodiment, a series of insulated wires 702

are wrapped around the outside of each shell, thus avoiding

any blockage of the light, as shown in Figure 7A. The

wires 702 may be charged to a potential while the shells

are held to a ground 704. Near one of the wires, the

presence of the grounded plane results in a dipole field

710, as shown in Figure 7B. The strong gradients present

in the dipole field may serve to collect even neutrally

charged particles.

[0036]   For an embodiment with a wire wrap pitch of 2mm

and wire size of 200micron held at 200V, a rough estimate

of capture time for a 100nm SiO_2 particle (density 2300

kg/m^3 (m_p = $1.2 \cdot 10^{-18}$ kg)) with a charge of 5eV is 0.1 ms,

and 0.1s for the same particle with no charge.

[0037]   The embodiments described above utilize magnetic

fields to mitigate debris. In alternative embodiments,

electric fields may be used to mitigate debris. For

example, in an embodiment, each collector shell may be

split into two conducting layers, which are separated by an

insulator 802, as shown in Figure 8. The reflective layer

804 is charged to a positive state and the non-reflective

side 806 to a negative state. This creates an electric

field 808 pointing away from each reflective surface 804,

and towards the backing of the neighboring shell. This

approach may work particularly well for positively charged

ions, carrying them away from the reflective surfaces and

towards the non-reflective surfaces. Positively charged

ions are known to be one of the primary sources of damage

of the collectors. However, this may not work as well for

neutrals as the field gradient would be relatively weak.

[0038]   For an embodiment with 10 cm long plates

separated by 1cm and a potential difference of 100V, rough

estimates suggest singly charged (1 eV) Xe atoms with

energy up to 2.5keV could be captured.

[0039]   In other embodiments, the wire and split-plate

approaches described above in connection with Figures 7A

and 8, respectively, may be combined in various ways. For

example, a split-plate approach may be used for a section

of the collector nearest the light source and wires may be

applied to a section farthest from the light source.

Alternatively, wires or bumps may be placed on the non-

reflective collector side to introduce larger field

gradients and thus increase the capture rate neutrals. In

another embodiment, electret fibers may be used instead of

wires connected to a power supply. Electret fibers are

permanently imbued with an electric dipole moment.

Electret fibers are commercially available, and are

produced by the mature process of polymer melt-blowing with

either corona charging or electrostatic fiber spinning. In

the latter technique, the fibers are continuously released

in liquid state out of a die into a region of a strong

electric field. After some distance the fiber crystallizes

with the electric field embedded in it. Fiber thickness

can reach below 1 micron, although 100 microns is used in

the present description for mechanical reliability. In

another embodiment, the backside surface of each collector

may be grooved or textured to assist collecting any

particles that are drawn to the surface. In yet another

embodiment, either charged wires or electret fibers could

be attached perpendicularly between the shells, forming a

web that would attract particles. A disadvantage to this

approach is that some light would be absorbed and fast

particles may make it through the web. However, negatively

charged particles would be attracted to the reflective

surface, making this approach favorable if such particles were in the minority.

[0040]   In an embodiment, debris-contaminant "foil traps", e.g., foil elements 902, may be positioned between the source 205 and the collector mirrors 210, as shown in Figure 9. The foil elements may be small, thin foils spaced apart from each other by, e.g., 1mm and spaced apart from the source by, e.g., 10-20mm. Typically, the debris particles travel in a jagged path characteristic of Brownian motion. This path makes the debris particles susceptible to striking, and being captured by, the foil traps.

[0041]   The outer and inner current-carrying shells may extend towards the foil trap and thus extend the magnetic field into the trap. The thinly spaced foils may capture ions only slightly deflected, giving the magnetic field more time to act on an ion.

[0042]   In the embodiments above, the magnetic field may be enhanced by incorporating ferrous materials into the various components.

[0043]   A number of embodiments have been described. Nevertheless, it will be understood that various modifications may be made without departing from the spirit

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and scope of the invention. Accordingly, other embodiments are within the scope of the following claims.